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Renewable and Sustainable Energy Reviews
7 (2003) 453–468

RENEWABLE & SUSTAINABLE ENERGY REVIEWS

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A review on the energy production, consumption, and prospect of renewable energy in China

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Received 14 April 2003; accepted 14 April 2003

Abstract

China is the second largest energy consumer in the world. This paper reviews the production and consumption of traditional and renewable energy in China over the past three decades. It also presents an overview on the research and development of renewable energy, such as solar, biomass, geothermal, ocean and wind energy in China. Study indicated that the usage of renewable energy in China shows a promising prospect in the near future, of which biomass is found to be one of the most promising renewable energy resources that have great potential for development in China.

Keywords: Energy consumption; Statistics; Renewable energy

Contents

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1364-0321/$ - see front matter
doi:10.1016/S1364-0321(03)00065-0

1. Introduction

Energy, like food and shelter, is a basic need of people throughout the world. Particularly in China, as a developing country with a population of 1.25 billion, energy is hugely needed for its fast economic growth (average annual GNP growth rate between 8% and 9%). While the economy is undergoing rapid development, it will be necessary to ensure rational utilization of natural resources and protection of the environment. It was put forward in the China's Agenda 21 [1] that the energy industry is fundamental to the national economy, and is of critical importance to socio-economic development and improvement of people's living standards. In an environment of a rapidly expanding economy, China's energy industry is confronted with dual pressures from economic development and environmental protection. These are primarily evidenced in the following: (a) the management and technology level of the energy industry in China is underdeveloped. Both the energy utilization and per capita energy consumption efficiencies are very low. There is a big gap [1] between energy supply and demand. Wastage of energy is also common; (b) China's energy structure is coal-based, with coal consumption amounting to 60% of total energy consumption. In the past several decades, coal, as well as other fossil fuels, petroleum and natural gas, have been the dominant fuel for combustion and refining to supply energy. However, cleaner energy constitutes only a small proportion of the total energy supply. Therefore, large quantities of pollutants and greenhouse gases (GHGs) are emitted, resulting in serious atmospheric and water pollution.

The consumption of conventional energy (coal, petroleum and natural gas) on one hand results in serious environmental pollution problems, and on the other hand faces with the danger of exhaustion. Nuclear energy also creates problems in treating and storing of the hazardous radioactive waste. In order to have a sustainable development in China, we must enhance the efficiency of the conventional energy generation and increase the proportion of renewable energy sources in the total energy budget. In this paper, an overview on the previous and current status of energy consumption will be given together with an analysis on the prospect of renewable energy in China.

2. Status of conventional, nuclear and renewable energy consumption in China

The growth of national economy and the progress of a society rely heavily on a stable supply of energy. Commercial energy used in China mainly comes from fossil fuels, so called conventional energy that includes coal, petroleum and natural gas. However, fossil fuels are greatly limited by their resources and will be used up in the future. It is estimated that as an important primary energy source, coal has played a key role in China's energy market in the past century. Until now, coal is still used dominantly in power generation in China. Table 1 shows the estimated nationwide primary energy consumptions from 1970 to 2000 [2–6]. The energy consumptions include commercial energy and non-commercial energy (such as rural biomass energy, etc.). It can be seen from Table 1 that the energy consumption greatly increased by 130% (from 342 MTOE in 1970 to 801 MTOE) over 10 years. The total primary energy consumption increased continuously and reached the highest at 1154 MTOE in 1997. Then it gradually decreased to 934 MTOE in 2000. This advancement trend of primary energy consumption resulted from the rapid growth of economy in the past two decades and the implementation of energy saving policy in recent years.

Non-commercial energy is normally not included in the nationwide energy consumption data in many energy statistic yearbooks. However, this energy is taken into consideration in the present paper in order to have a more realistic energy statistics. Most of the non-commercial energies are renewable energies. The proportions of all kinds of energy consumptions between 1970 and 2000 in China are depicted in Fig. 1. It is astonishing that the proportion of renewable energies used is remarkably high, as compared with other energy sources. For instance, the percentages of renewable energies dropped from 40% in 1970 to 19% in 2000. Among those renewable energies (biomass, solar, wind, geothermal, and ocean energy), biomass energy plays an important role in China's economic development. Almost 100% of the renewable energy consumed in China is biomass energy, particularly in rural areas where direct

Table 1
Nationwide primary energy consumptions (1970–2000), MTOE*

	Coal	Petroleum	Natural gas	Hydro	Nuclear	Renewables[a]	Total[b]
1970	165.8	30.1	1.8	7.2	0.0	137.1	342
1980	465.3	133.4	20.0	25.8	0.0	156.9	801
1990	526.5	114.7	14.5	35.2	0.0	175.2	866
1997	691.4	197.3	16.4	60.0	3.7	185.0	1154
1999	573.0	199.8	23.9	57.2	4.5	180.3	1039
2000	474.4	201.1	22.6	50.5	4.5	181.2	934

* MTOE: million tons of oil equivalent.
[a] Include biomass, solar, wind, geothermal and ocean energy.
[b] Estimated based on published data [2–6].

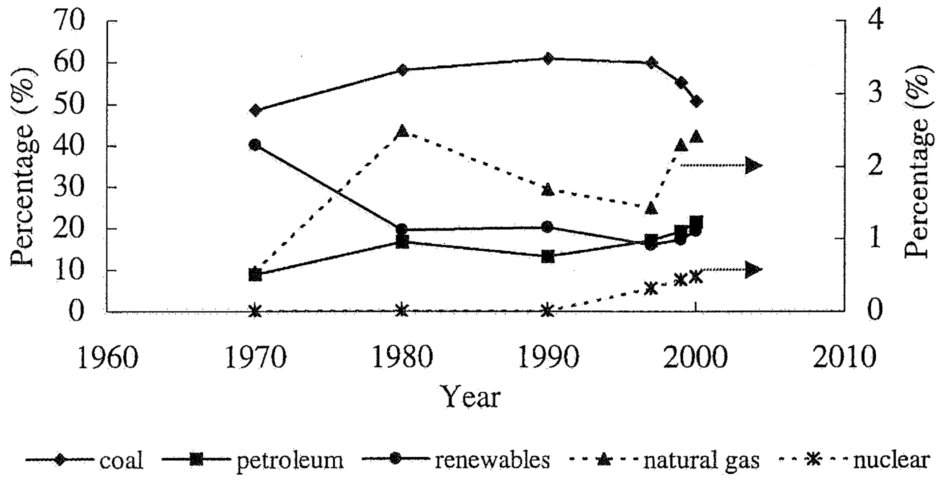


Fig. 1. Composition of energy consumption in China.

combustion of biomass was the major source of energy. However, the technology of biomass utilization in China is still lacking behind that of the developed countries. If traditional biomass energy is used by modern technology, the conversion efficiency will be increased, and the proportion of biomass energy in the primary energy consumption structure will be further improved. Today, renewable energy represents more than 10% of primary energy production of EU-15 (European Union). In Austria, Finland and Sweden, almost two-thirds of their primary energy production is from renewable sources [7:p.1, 8]. The comparison of energy consumption between China and the world are listed in Table 2 [9–11].

Table 2
Primary energy consumption profile for China and the world in 1997

	World		China	
	Amount (MTOE)	Proportion (%)	Amount (MTOE)	Proportion (%)
Coal	2122	22.0	691	59.9
Petroleum	2940	30.5	197	17.1
Natural gas	2173	22.5	16	1.4
Nuclear	579	6.0	4	0.3
Hydro power + renewable energy	1833	19.0	245	21.2
Total	9647	100.0	1154	100.0
Population (million)	5847		1240	
Per capita energy (TOE)	1.65		0.93	

It can be seen that the primary energy consumption of China in 1997 is 1154 MTOE (Table 1) and exceeds 10% of that of the world (9647 MTOE). China is the second highest energy consuming country in the world, just behind the USA. However, because of the large population, the per capita primary energy consumption of China is just half that of the world's average level. Coal played an important role in the energy consumption of China. About 60% of the consumed energy in China is from coal, which constitutes about 22% of the world's energy consumption. On the other hand, a small amount of natural gas (1.4%) was utilized in China as primary energy before 2000 as compared to 22.5% of the world. Obviously, natural gas combusts cleaner than coal and there is a large reserve of natural gas in China. However, the technology of exploration, exploitation, and utilization is still at a low level. Moreover, due to the advance in technology in the usage of natural gas, the proportion of natural gas usage in China is in an upward trend.

In recent years, China has paid more attention to developing its energy industry to meet the high energy demand, to cope with the rapid growth in national economy and to improve people's living standards. The energy production and proportions of various sources in China between 1970 and 2000 are listed in Table 3. Coal energy is the biggest part of energy sources and coal-mining industry is the most important energy industry in China, while the oil, natural gas and hydro-electric industry have been greatly developed only in the last three decades. From 1970 to 1997, the total primary energy production had been increased by 4.5% per annum. In 1970, the primary energy production was 354 MTOE, which rose to the highest at 1116 MTOE in 1997 and dropped to 912 in 2000. The proportion of renewable energy decreased from 40% in 1970 to 16% in 1997, and then increased to 19% in 2000. Before 1997, biomass was still the main source of renewable energy in China. However, its utilization technology was at a low level. With the advance in science and technology, the efficiency of biomass utilization has been improved recently. Comparing the data in Table 3 with those in Table 1, it can be seen that the primary energy consumption in 1997 exceeded the production of energy by about 38 MTOE. There is a big shortage in the energy market, even though China has done its best to develop its energy industry in recent years, that is, the energy production cannot meet the demand due to a poor base facility and shortage in investing the energy industry in China. China has become a net energy imported country of which the amount of

Table 3
Percentage distribution of nationwide primary energy production in China (1970–2000)

Year	Total energy production (MTOE)	Coal	Petroleum	Natural gas	Hydro power	Nuclear	Renewable energy
1970	354	50.1	8.6	0.7	1.9	0.0	38.7
1980	803.1	51.4	17.6	2.2	2.8	0.0	26.0
1990	902.9	59.8	15.3	1.6	3.9	0.0	19.4
1997	1115.5	61.6	14.4	1.7	5.4	0.3	16.6
1999	955.1	55.0	16.8	2.5	6.3	0.5	18.9
2000	911.7	53.1	17.4	2.4	6.7	0.5	19.9

energy imported is larger than that of energy exported. The shortages of oil and natural gas may be alleviated by the use of renewable energy resources. The development and application of renewable energy will therefore improve the energy security and be a sustainable development.

3. An overview of different renewable energies usage in China

There is a long history of renewable energies usage in China, including biomass, solar, geothermal, ocean and wind energy. Renewable energy technologies produce marketable energy by converting natural phenomena/resources into useful energy form. These resources represent a massive energy potential, which greatly exceeds that of fossil fuel resources [12]. The usage of renewable energy resources is a promising prospect for the future as an alternative to conventional energy. However, except biomass energy, the proportion of other renewable energy used is still much smaller than that of the conventional energy resources. The following is an introduction of various renewable energies used in China in recent decades.

3.1. Solar energy

Solar energy in China is abundant. In western China, there are more than 3000 sunshine hours per annum. Taking into account the vast areas and the low population density, small energy facilities such as photovoltaic systems are more cost effective than the expansion of existing electricity grid. Therefore, photovoltaic system will play an important role in the west's exploitation of mainland China.

The research and development of photovoltaic in China can be dated back to 1958. It began to enter into the application stage in 1970s, but it was not actually commercialized until the mid 1980s, when two single crystalline silicon solar cell production lines were introduced and the large-scale utilization period commenced. Since 1993, the output of domestic crystalline silicon solar cells soared by 20–30% annually; the total installed capacity of photovoltaic systems in China was approximately 22 MWp at the end of 2002 [13]. Compared with traditional energy sources, the installed capacity of solar energy in China is very small.

The higher cost and shortcoming of lower energy density (approximately 1 kWp/m^2) and time dependency limit the application of solar energy. However, progress continues to be made in the photovoltaic industry with reasonable scope for further improvement in cost-reduction in the near future. The performance gap between laboratory and industrial devices is being narrowed. This will result in the birth of a new generation of low-cost photovoltaic systems with high performance.

3.2. Wind energy

China has been harnessing wind energy for hundreds of years. From ancient Holland to China, windmills, making use of wind energy, had been used for pumping water and grinding grain. Today, the windmill's modern equivalent, wind turbine,

generates electricity from wind energy. Advanced wind turbine technologies are able to produce electricity for homes, business, and even utilities.

Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are built close together to form a wind farm. Several electricity providers in China today use wind farms to supply power to their customers. (e.g. Nan Ao Wind Farm, Shan Wei Wind Farm).

3.3. Ocean energy

Ocean energy includes various kinds of applicable low-density ocean phenomenon, such as heat gradient, tidal and wave. The technologies of ocean energy utilization are still under development. In China, the utilization of tidal energy started in the mid 1950s. Several tidal power stations were built in Fujian Province and Guangdong Province pumping water for irrigation. After then, it entered the phase of tidal electric power generation. The development of tidal power in China could be generalized into three different stages. The first stage could be dated back to 1958. At that time, 40 small tidal power stations with a capacity of 12 kW were built. Another dozen tidal power stations with larger capacities were built in the second stage around 1970. Among them, Jiangxia Tidal Power Plant and Baishakou Power Plant were the largest ones with a capacity of 3000 kW. Unfortunately, most of the tidal power stations built in these two stages were out of service due to wrong siting, backward technology, conflict service between irrigation and navigation purpose, and inconvenience in use. The third stage was started at the end of the 1970s emphasizing further improvement and scientific management on the existing stations, optimizing their economical and social benefits. The Xingfuyang tidal power plant in Pingtan Island, built in 1985 with a total installed capacity of 1.28 MW, was put into operation in May 1989. At present, there are seven tidal power stations and one tide flood power station in operation with a total capacity of 11 MW. The feasibility study of a 10 MW intermediate experimental tidal power station in Jiantiao Port of Zhejiang Province and Daguanban Port of Fujian Province has been worked out. The planning of the Maluanwan Tidal Power Plant is under way.

Further development of ocean energy conversion in China follows specific strategies in accordance with China's special conditions as follows: (1) The location of the installation should be carefully sited in those areas where conventional energy is not available; (2) In order to make tidal or ocean energy conversion become viable, the design of ocean energy conversion systems should be diversified for meeting different uses and demands, and the economics consideration should be seriously taken; (3) In the near future, it will not be feasible to build large-scale commercial ocean power generation systems in China. Instead, it will be more feasible to build small- and medium-scale system in coastal areas where the electricity grid does not reach.

3.4. Geothermal energy

Geothermal energy is the energy contained as heat in the Earth's interior, which is the only renewable energy source not originating from solar energy. The origin of this heat is related to the internal structure of our planet and the chemical processes occurring there. Geothermal energy includes direct use of heat, electricity production and geothermal heat pump.

In modern direct-use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well, whereas a mechanical system directs the hot water to a heat exchanger, controls, and delivers the heat directly for the intended use. A disposal system then either injects the cooled water underground or disposes of it at the surface.

There are three types of geothermal power plants: dry steam, flash steam, and binary cycle. Flash steam power plants are the most common in the world. They use geothermal reservoirs of water with temperatures higher than 180 °C. This very hot water flows up through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils into steam. The steam is then separated from the water and used to power a turbine/generator. Any leftover water and condensed steam are injected back into the reservoir, making this a sustainable resource.

Small-scale geothermal power plants (under 5 MW) have the potential for widespread application in rural areas in China, possibly as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

Geothermal heat pumps can heat and cool buildings using shallow ground. The system basically consists of three parts: a ground heat exchanger, a heat pump unit, and an air delivery system (ductwork). The heat exchanger is basically a system of pipes (called a loop), buried in shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground.

3.5. Biomass energy

During the growth of plants, water and CO_2 are absorbed and transformed into organic matter (carbohydrates) through photosynthesis in the presence of sunlight. The organic matter that makes up these plants is known as biomass. Biomass contains lots of energy that can be used to produce heat, electricity, transportation fuels, or chemicals.

We have used biomass energy for thousands of years, ever since human beings started burning wood to cook food or to keep warm. Today, wood is still our largest biomass energy resource. However, many other sources of biomass are used nowadays including plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. Even the fumes from landfills can be used as a biomass energy source.

The use of biomass energy has the potential to greatly reduce our greenhouse gas emissions. Biomass generates about the same amount of carbon dioxide as fossil fuels, but every time a new plant grows, carbon dioxide is removed from the atmosphere. The net emission of carbon dioxide will be zero as long as plants continue to be replenished for biomass energy purposes. These energy crops, such as fast-growing trees and grasses, are called biomass feedstocks. The use of biomass feedstocks can also help increase profits for the agricultural industry.

The main processes by which energy may be obtained from biomass include direct combustion, pyrolysis, gasification, hydrogasification, liquefaction, anerobic digestion, alcoholic fermentation, and transesterification. Each technology has its own advantages, depending on the biomass source and the type of energy needed.

4. Prospects of renewable energy in China

Even though renewable energies only account for less than 10% of the world's total energy consumption currently, the potential of renewable energies is enormous due to its unlimited supply and also its cleanliness in use. Once the Kyoto Protocol is fully implemented by all the signatories, the incentive of using renewable energies will be greatly increased.

Today, mankind faces two major global climate problems: global warming (or the greenhouse effect) which is mainly caused by emissions of CO_2, and acid rain, caused by emissions of SOx as well as NOx. Both problems are caused by the use of fossil fuels (coal, petroleum, and natural gas), which accounts for approximately 80% of Chinese nationwide primary energy consumption. Nevertheless, the fossil fuel resources will be totally drained in the near future. From the 1992 survey data of related Chinese government divisions [14], total oil reserve was estimated to be up to 60 billion tons, recoverable oil reserve to be 15 billion tons and the explored reserve to be 3.3 billion tons in China; while the total natural gas reserve was about 30 TM^3 (10^{12} M^3), the recoverable reserve was 6.4 TM^3 and the explored reserve was 1.4 TM^3. The total coal reserve was about 4500 billion tones with an explored reserve of 985 billion tones. Based on these data and the planned economic grow rate, it was estimated [15] that the oil reserve would be exhausted by 2040, natural gas by 2060 and coal by 2300. The known worldwide reserve of coal would be consumed in about 220 years based on the annual consumption in 1998 [16,17]. On the same basis, the known reserves of petroleum would be used up in about 39 years, and the natural gas in 63 years [17,18]. After the petroleum crisis happened in the 1970s, focus has been concentrated on the gasification and liquefaction of coal. However, no remarkable results have been achieved after 30 years. Complex technologies and huge investment limit the extensive utilization of gasified and liquefied coal.

The other pressure of reducing use of fossil fuels comes from environmental protection. The Kyoto Protocol, agreed with 171 participating countries, introduced a set of legally binding limitations on emissions from the world's 39 industrialized countries [7: p. 64]. However, the GHG emissions create a global problem that can only be resolved through global co-operation and a common effort. GHG emissions

in the future will come not only from industrialized countries but also from developing countries, due to the rapid increase in energy consumption as a result of modernization. In the Johannesburg summit meeting for sustainable development in September 2002, the Chinese government endorsed the Kyoto Protocol. This indicated China's active attitude in participating the international co-operation for the world sustainable development.

Although nuclear power has been developed for more than five decades providing about 20% of the world's electricity requirements today and has reached a certain technological maturity, it is no longer acceptable in the USA and parts of Europe due to the problems caused by radioactive waste. The other alternative energy resource, hydro energy, has also been criticized in many countries due to the negative impact of man-made dams and reservoirs on the environment and biodiversity. Therefore, neither of these two alternative energy sources have promising prospects for the future.

The role of energy has often been overlooked in sustainable development strategies. In fact, energy is at the heart of the sustainable development challenge, since nearly all activities in our societies depend upon adequate supplies of energy [19]. Achieving a more sustainable energy path will contribute significantly to the realization of the sustainable development of society, economy and environment. The use of renewable energy sources and rational use of energy are the fundamental vectors of responsible energy policy for the implementation of sustainable development and national energy security strategy.

Development and utilization of renewable energy resources has becoming an important component of the world energy strategy for sustainable development. Many developed and some developing countries take it as their basic choice for 21st century energy development strategy. There are abundant renewable energy resources in China. It was reported [20] that the average solar radiation exceeds 600 kJ/cm^2 over two-thirds of the mainland area. The annual solar energy absorbed in China is equivalent to 17 tera TCE (ton of coal equivalent, 1 TCE = 0.778 TOE). There are remarkable prospects for the utilization of solar energy. The total amount of wind resources is about 1.6 billion kW, and the applicable wind energy is about 0.25 billion kW. The perspective reserve of geothermal energy is estimated to be 135.4 billion TCE, while the proved reserve is approximately 3.2 billion TCE. Biomass energy also has an abundance of resources, for example the annual amount of crop residue is equivalent to 310 million TCE, the amount of firewood is equivalent to 130 million TCE, in addition to the urban refuse or municipal solid waste, the total amount of biomass resources is equivalent to 650 million TCE [20].

Through several decades of research, development and demonstration, great advancements have been achieved in renewable energy technologies, markets have been broadened and industrialization has been formed to a certain scale. Until the end of 1998, a lot of achievements have been obtained in the utilization of renewable energy and construction of rural energy [21]: the total primary energy consumption reached 1.36 billion TCE, and the consumption of renewable energy exceeded 0.2 billion TCE; 185 million firewood and coal saving stoves had been popularized nationwide; anaerobic digesters had been popularized to 6.88 million homes, 748 of

middle- and large-scale rural anaerobic digestion projects and 50,000 of urban sewage digesters had been developed; 200 of crop residue gasification stations had been built to supply fuel gas for 30,000 homes; 7.89 million m^2 of solar heaters, 240,000 of solar stoves, 5.37 million m^2 of passive solar greenhouses had been developed, and 11 MW of photovoltaic cells had been installed; 21 wind power plants with a total capacity of 224 MW had been set up, 155,000 of microwind turbines (annual electricity generation is 35.9 million kWh) had been installed, but the capacity of total installed wind power facilities was less than 0.1% of that of the total installed electricity generating facilities, which was approximately 250 million KW; the total installed geothermal electricity facilities reached 35 MW, therein, 25 MW generators were installed in Yang Bajing, Tibet, 45.4 km^2 of geothermal greenhouses had been built. At the end of 2000, 50 MW of biomass power generation systems had been installed nationwide.

The World Energy Council [21] estimated the status of renewable energy in total worldwide primary energy consumption at 2020 based on the data of 1985 and two different growth rates. The result is shown in Table 4. As can be seen, biomass energy plays a very important role in worldwide energy among those renewable energy resources. The other renewable resources, such as solar, wind, ocean and geothermal energy, only have the proportion of 1.5% in the case of lower growth rate.

5. Current researches on renewable energy

To increase the competitive ability of renewable energy in the energy market, much research has been carried out in the field of solar, wind, geothermal, ocean and biomass. The Chinese government is making favorable policies for the middle- and long-term development of renewable energy resources.

Three state agencies, the Ministry of Science and Technology (MOST), the State Development and Planning Commission (SDPC), and the State Economic and Trade Commission (SETC) have jointly set up a major project “Program on New and

Table 4
Contribution of renewable energy in the world primary energy consumption

	Amount (MTOE)			Proportion (%)		
Year	1985	2020 M[a]	2020 L[b]	1985	2020 M	2020 L
Hydro power	445	1043	848	5.8	7.7	7.3
Biomass energy	880	1055	1310	11.5	7.8	11.3
Other renewable energies	19	365	170	0.2	2.7	1.5
Sum	1344	2463	2328	17.5	18.2	20.1

[a] Medium growth rate.
[b] Lower growth rate.

Renewable Energy Development in China (1996–2010)". The major targets of this program [22] include 13.4 million hectares of fuel wood plantation, 4 billion m^3 of biogas supply to 12.35 million households, 117 GWh electricity from small hydro, 4.67 million TCE of solar energy, 1000–1100 MW of wind power capacity and 50 MW of tidal power capacity. The same three organizations have also launched a photovoltaic program ('Sunlight Program'), which will run up to 2010 and is expected to upgrade the country's manufacturing capacity of polycrystalline and other advanced silicon technologies; to establish large-scale PV and PV/hybrid village power demonstration systems, home-PV projects for remote areas; and to initiate grid-connected PV projects. Other notable programs include the "Brightness Program" and the "Ride the Wind Program". The first has been instituted by the SDPC through the bilateral and multilateral assistance aiming to install several solar and wind power systems in the northwest part of China. The second (also known as Chengfeng Program) is a bilateral co-operation program, which has already installed a total of 110 MW wind turbines in various parts of China at the end of 1998. Besides these programs, a GEF/World Bank renewable energy development program is also in the pipeline. This program will support the installation of 200 MW of wind farms; installation of 200,000 PV solar home systems by private firms and strengthening of institutional capacity, business skills and project management in the field of renewable energy in China. Improving the manufacture of wind turbine parts and assembly technology will be the focus in the research and development of wind energy [23].

Since the 1980s, wave energy research has been concentrated mainly on fixed and floating oscillating water column and pendulum devices. In 1995, Guangzhou Institute of Energy Conversion (GIEC) of Chinese Academy of Sciences had successfully developed a symmetrical turbine wave power generation device for navigation buoys. Over 650 units have been deployed in the past 13 years, mainly along the coast of China with a few exported to Japan [24]. The near- and middle-term research focused on ocean energy should be in the tidal electricity generation technology, 100 KW scale wave and current demonstration units, and experimental units for the integrated utilization of temperature [25]. However, the environmental disruption caused by wave energy devices in the shoreline/near-shore areas will necessitate an extensive and expensive consultation process, because of the number of statutory bodies that have an involvement in the coastline and surrounding waters of China, the effect of tidal energy land works on local ecosystem should also be considered [26]. The utilization of wave energy in an isolated island will also be a research hotspot in the future.

Research on the exploration, exploitation and conversion technology will be the important directions for the utilization of geothermal energy, though the development and utilization of the geothermal energy has a minor impact to the environment due to the emission of H_2S. The long-term environmental impact of developing and utilizing geothermal energy needs to be further studied.

Biomass energy is an old energy resource used by mankind for thousands of years. Today, wood is still our largest biomass energy resource, but many other biomass sources can now be used, including plants, residues from agriculture or forestry, and

the organic component of municipal and industrial wastes. Even the fumes from landfills can be used as a biomass energy source. Today, bio-energy is available 24 h a day, 7 days a week. Other forms of renewable energy, such as solar or wind power, have lower availability since they are produced only in the presence of sunlight and wind blowing.

In order to prompt the development of new and renewable energy resources, in 1995, three commissions, i.e. SSTC, SPC and SETC, completed a report "An Essential for Developing New and Renewable Energy Resources in China" giving the outline of the plan "Planning for 2010" [27]. This document has the objective that by 2010, firewood forest area will increase to 1340 hectares or produce 1270 million tones of firewood per annum; the total energy production will be 4.9 million TOE by developing biomass energy technologies, such as efficient burning, briquetting, gasification and liquefaction, the total amount of biogas users will surge to 12.35 million households and biogas production will reach 4.0 billion m^3 or 2.2 million TOE. To achieve this objective, a development plan is being drawn by CBDC under MOST for the 10th Five Year Plan (2000–2005) [27]. Table 5 shows the plan in detail. A high technology development program had been conducted in China from 2001 to 2005, named as "863 Research Program". In this program, some new technologies will be developing as key biomass projects in the next decade (Table 6).

Bio-energy holds great promise for the future in China. But to realize this promise, key challenges must be met. First, the cost of bio-energy needs to be lowered. As long as the conventional fossil fuels cost less in producing electricity or less costly as transportation fuels than biomass, people will be reluctant to invest in bio-energy. We must also ensure that increasing our use of bio-energy will not adversely affect our environment. Finally, we must work together to facilitate the growth of an integrated bio-energy industry that links resources with the production of a variety of energy and material products.

Researchers are particularly interested in improving small systems sized at 5 MW or less [28]. These so-called modular bio-power systems can use direct combustion, co-firing, or gasification for power generation. They are well suited for generating bio-power from locally grown resources for small towns, rural industries, farms, and ranches. Modular systems may be a good choice where power lines are not available. Clusters of modular bio-power systems in rural areas may eradicate the need for power companies to build larger, more expensive power plants. Biomass is also a renewable source of transportation fuels. These renewable fuels, called bio-fuels, produce fewer emissions than petroleum fuels. Bio-fuels also can help us reduce our dependence on the limited fossil fuels. 1–5 MW scale decentralized gasification and power generation systems, and bio-fuels (such as biodiesel, methanol, ethanol, dimethyl ether, and Fisher–Tropsch hydrocarbon) derived from biomass will be a promising research direction in the middle–long term. Measures to lower the cost and effect to the environment will be important in the production of bio-fuels.

Table 5
Priority projects in China's "10th Five year Plan"

Projects	Scales	Proposed Institutes	Location
Gasification			
4–5 MW electricity generation system by biomass gasification	12,000 MWh electricity per annum	Guangzhou Energy Institute of CAS Liaoning Institute of Energy Resources	Guangdong Yingkou
Study on standardization and commercialization of electricity generation system by biomass gasification	6 series 60–160 kW	Shandong Institute of Energy Resources	Shandong
		Nanjing Institute of Forest Chemical Products	Nanjing
		Secretary Office of China Biomass Development Center	Beijing
Biogas			
2 MW electricity generation system by biogas	6000 MWh electricity per annum	Hangzhou Institute of Energy and Environment	Hangzhou

Table 6
Biomass research projects in China's 863 programs

Projects	Scales	Proposed Institutes	Location
Biomass electricity generation			
5 MW electricity generation system by biomass IGCC	14,000 MWh electricity per annum	Guangzhou Institute of Energy Conversion	Guangzhou
Liquid fuels			
Biomass liquid fuel technology	Including alcohol, pyrolysis and plant oil fuels	East China Science and Technology University	Shanghai

6. Conclusions and perspectives

In China, which has a population of over 1.2 billion, an adequate amount of energy is hugely needed to maintain its GNP grow with a rate of between 8% and 9% per annum. However, due to the shortage of primary energy, China has become a net energy imported country in recent decades. Its primary energy consumption is the second highest in the world, just behind the USA.

It is well known that the consumption of conventional energy and nuclear energy resulted in serious environmental pollution problems. Apart from that, fossil fuels are also facing the danger of exhaustion. In order to keep a sustainable development, China should enhance its efficiency in using the conventional and nuclear energy, and increase the proportion of renewable energy sources in the total energy budget.

Renewable energies, including biomass, solar, geothermal, ocean and wind energy represent a massive energy potential, which greatly exceeds the potential of fossil fuel resources. The usage of renewable energy resources shows a promising prospect in China in the future as an alternative to the conventional energy. Of the different renewable energy resources, biomass energy plays an important role in the energy budget of China. Almost 20% of the primary energy consumed in China is biomass energy. Despite its massive usage, the technology of biomass utilization is still in the development stage. If traditional biomass energy is utilized using modern technology, the energy conversion efficiency can be greatly enhanced, and the proportion of biomass energy in the primary energy structure will further be improved.

The Chinese government has made policies and budgets for the research, development and demonstration for renewable energy projects. It shows great prospects for the renewable energies in the sustainable development of society and economy. In the medium term, biomass energy is one of the most promising renewable energy resources in China.

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